SOME ADDITIONS TO THE KNOWLEDGE OF THE GEOLOGY OF KALGOORLIE, WITH SPECIAL REFERENCE TO THE OCCURRENCE OF A PORPHYRITIC OLIVINE PICRITE.

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Read 12th September, 1922.

The mines of the Golden Mile, *i.e.*, of an area of about one square mile, round and including the town of Boulder, comprise, as is well known, some of the richest in the world. The characteristic rocks of the mines are a greenstone which is an altered form of a quartz-dolerite, an albitic porphyry, and a graphitic schist or slate. The gold occurs in lodes or mineralised zones in the country rock and these lodes are chiefly the rather uncommon type known as composite lodes, which are really zones consisting of small fissure fillings of fairly parallel strike from which an extreme impregation and replacement of the country rock proceeded. Investigation has shown that no sharp boundary with the country exists, but that on either wall mineralisation gradually diminishes and the lode material passes into the unaltered green rock. In depth, these composite lodes extend at least as far as the bottom levels in the chief mines, and as the result of the recent discovery of fairly rich ore at a depth of about 3,000 feet in the Ivanhoe Mine, it is certain that the limits of ore deposition have not yet been reached.

In view of the phenomenal richness of the mines and of the width, depth and number of lodes, it was held by mining men early in the history of the field that it would be most remarkable if other mines comparable in importance and geologically similar were not to be found to the south of the Golden Mile group, and for years attempts were made by means of shafts and bores driven from the bottom of the shafts to pick up the continuation of the lodes. These attempts, however, met with no success, for south of a line drawn through Hannan's Star, the Black Crow, the Starlight and the Lake View Extended Leases, no composite lode was ever discovered.

Prospecting, however, for this continuation was and always has been attended with unusual difficulties. Even to a greater extent than in other parts of the Eastern Goldfields, and owing to the terrestrial and arid climate experienced by the interior of the State for countless years and to the peculiar type of weathering and decomposition the rocks have undergone in consequence of this

climate, there is a covering of brownish or reddish clayey material ranging from a few feet to at least 150 feet in thickness all over the country as far south as Hannan's Lake. There are few outcrops and even these are in a very decomposed condition, and there are on the surface practically no indications whatever of the nature and structure of the rocks below the covering.

As a result, therefore, of these peculiar geological conditions prospecting for the southward extension of the auriferous lodes was until recently largely confined to the sinking of shafts on the line of strike of the lodes and boring at inclined angles to the dip from the bottom or sides of these shafts. Much valuable information about the nature of the rocks was obtained by these methods and it was on this information that geological maps of the country to the south of Boulder were ultimately prepared, and considering the material available these maps have proved to be fairly indicative of the geological structure and constitution. As, however, from the very nature of the methods—as the shafts put down are not numerous, as many of them are of shallow depth, and as between most of them there exist considerable intervals of ground untested—the information at hand has always been more or less fragmentary and accurate delineation of the boundaries of the different formations has been impossible. In consequence, it has always been recognised that any new systematic scheme of prospecting would undoubtedly reveal additional facts which would cause some alterations in the existing maps.

The problem of picking up the continuation of the Boulder lodes is really one of finding the prolongation of the altered quartz-dolerite belt and of discovering sheared and mineralised zones in it As the method of investigation by shaft-sinking is very expensive and the results of the work are comparatively small, in order that fairly large areas of country could be tested, some other methods had to be adopted, and within the last two years more or less systematic prospecting has been carried out south of Boulder by means of the diamond drill.

The materials on which this Paper is based are chiefly the bore cores from the bores put down by means of these drills.

Within the last two years boring has been carried out in five different localities which have been marked on the accompanying plan:

1. On the Maylands Lease on the fringe of Hannan's Lake.
2. On Reserve 288H, Lease (5220).
3. On the Lady of the Lake Lease (5083), situated about one mile and three-quarters S.E. of the Great Boulder Mine.
4. On Lease 5072, Talisman; [5178] Bruce, and 5177.
5. On the British Flag Lease (5310).

1. *Maylands Lease.*—Boring on this lease was carried out by the Golden Ore Channel, Ltd., on sites fixed in part at least as the result of indications given by the divining rod. Three bores were drilled, the first, a vertical one, to 1,075 feet, the second, inclined at 75deg., to 1,316 feet, and the third, inclined at about 60deg., to 861 feet. Nothing to warrant the sinking of a shaft was found in any of the bores.

The rock of the three cores is essentially the same throughout, though in characters of minor importance it shows a considerable range. As a whole it is a dark-greenish or dark-grayish rock with white or pale-grayish spots that occur throughout the core from top to bottom, though they are much more common in some parts than in others. Commonly it is a porphyritic rock with white phenocrysts of felspar up to a quarter of an inch square and rare phenocrysts of quartz in a dark-gray ground-mass. In places, however, it is almost white, in others it is very dark green, in others again grayish-green, sheared, chloritic, and with small phenocrysts of felspar noticeable only with difficulty. Under the microscope the rock consists typically of well-shaped phenocrysts of turbid felspar, small phenocrysts of greenish hornblende and rare phenocrysts of quartz in a ground-mass composed of small squares, laths and grains of felspar, some granular calcite and minute scales of greenish chlorite. The species of felspar present are difficult to make out owing to the turbidity of the crystals which is due in part to kaolin, in part to granular calcite, in part to minute scales of muscovite. The commonest species, however, appears to be a plagioclase about oligoclase-andesine. The hornblende is in square or rectangular prisms, is of a rather pale-green colour, and in some crystals shows the orthopinacoidal twinning. Some forms are chloritised, others both chloritised and carbonated.

Some varieties of the rock are without hornblende, and containing as they do a considerable amount of quartz as phenocrysts, they very closely approximate in composition and structure to normal quartz-porphyries. Other varieties have neither quartz nor hornblende and closely resemble the albitic porphyries of other parts of the field. In a few places in the cores there are hornblende phenocrysts but no quartz.

A peculiarity of the rock is the occurrence in places of patches which from their irregular outline and paler colour appear to be xenoliths or enclosures of a foreign rock. Examination of these, however, proves them to be in all respects identical with some variety of the main body, and their occurrence is probably due (a) to the proximity of a junction of the rock with some other type, (b) to their being the first portions of the molten magma to be chilled and solidified, and (c) to the incorporation of these first

solidified portions in the molten or viscous rock and the ultimate solidification of the whole without movement, and so swiftly, that the molten magma had not time to re-act on the first-cooled portion.

The rock is typically a quartz-hornblende-porphyrite which is very similar to the hornblende-porphyrite already described from Bulong.

In the No. 2 Bore, at a depth of 909 feet, there occurs a marked change of country, the porphyrite giving way to a black graphitic schist or slate which is in places considerably brecciated. This rock is most probably the southward extension of the graphitic slate met with at a depth of 210 feet in the old Dingo Lease between Hannan's Lake and Boulder City. The relations between it and the porphyrite are of interest. For several feet before the main body of the graphitic slate is met with, small dead-black graphitic fragments make their appearance in the porphyrite, a fact which shows that the porphyrite has caught up these fragments when in a viscous state, and is consequently younger than the graphitic rock. The fact, too, that there are several abrupt changes from the graphitic slate to porphyrite and *vice versa* between 909 feet and about 1,200 feet suggests that the drill has gone down close to the junction of the two rocks and that this junction is somewhat irregular.

The graphitic slate shows no evidence whatever of having been derived from a quartz-dolerite by extreme shearing and impregnation by carbon. Both in composition and in structure it more closely resembles a true sedimentary slate than either a porphyrite or a greenstone.

In the No. 3 Bore, at a depth of 668 feet, the graphitic rock appears and shows at intervals to 679 feet.

2. *Reserve* 288E, *Lease* (5220).—Two bores were put down by the Golden Ore Channel Company on this Reserve, the first to 550 feet and the second to 313 feet 6 inches.

The rock from top to bottom of both bores is an albite porphyry or porphyrite in places showing quartz phenocrysts. It is in part sheared, in part sericitised and carbonated, and in part stained brown or brown-red by hydrated oxide of iron. In a few places some fine granular and cubic iron pyrites is present, and a few quartz veinlets cut through the rock mass. A rock identical with this has already been described by the writer in an article on the Petrology of the North End, Kalgoorlie, published in the London Geological Magazine, and no further description is therefore necessary.

3. *Lady of the Lake Lease.*—Mr. Arthur Williams, as the result of certain indications which he claimed to have obtained by the use of the divining rod, put down, largely at his own expense,

two bores on this lease. The core from the first of these, which went down only to 100 feet, was not officially examined. That from the second was a graphitic slate to a depth of 478 feet, but at this depth the slate gave place abruptly to an albite porphyry identical with that from the Golden Ore Channel Company's Reserve 288H, and with that already described in the article on the Petrology of the North End. The slate exhibited in places an incipient knotted structure, which is undoubtedly due to partial metamorphism and partial production of secondary minerals such as andalusite, caused by the intrusion of the porphyry. Both under the microscope and from chemical analysis the rock appears to be much more closely allied to a sedimentary slate than to a graphitised chlorite schist of igneous origin.

4. *Leases* (5072) *Talisman*; (5178) *Bruce*, [5177].—After his failure in the Lady of the Lake Lease, Mr. Williams, acting on the advice of the writer, again began boring in the leases just mentioned and some considerable distance nearer the line along which the Boulder lodes seem to die out. He has put down three bores, the first to 761 feet, the second to 447 feet, and the third, at his own expense, to about 100 feet. All three cores consist from top to bottom of amphibolised quartz-dolerite that has been more or less chloritised and which is essentially the same as the epidiorite that occurs in proximity to the Warden's House at Kalgoorlie. This epidiorite has already been described by the writer in Bulletin 69, G.S.W.A., pp. 25-26. The rock of the cores is also similar to the country rock of the Golden Mile, but, though it is in places slightly sheared, in places bleached and slightly mineralised by pyrites, in no part of the cores is it both sheared and mineralised, and therefore no lode material similar to that of the Boulder mines has yet been found in it. The bleached rock is almost white, yellowish or pinkish in colour, much carbonated, and shows leucoxene as small purplish-gray patches. The bleaching is caused by the action on the rock mass of solutions from below which break up the ferromagnesian mineral, produce a partial carbonation of the rock and form pyrites from the iron oxide left after the destruction of the ferromagnesian. This action has taken place both in the mines of the Golden Mile and in some of those of the North End, but in the former tellurides of gold were produced as well as pyrites.

5. *The British Flag Lease* (5310E).—One bore has been put down on this lease on a site chosen by Dr. Laver, of Kalgoorlie, his scheme being to bore eastwards at an angle of 45deg. and to a depth of 550 feet.

As the results of the examination of the core are very interesting from a geological point of view, a short general account of them must be given.

From the surface to a depth of 267 feet the rock passed through was the albite porphyry already mentioned. At this depth, however, the porphyry begins to show thin black strings and veins which become more and more common until at 267 feet 9 inches there is a sudden change from the porphyry to a rather fine-grained black rock. The latter persists to a depth of 308 feet and then gives place abruptly to the porphyry which contains the black strings and veins as before. From 308 feet to 314 feet the rock is porphyry, but at 314 feet the black rock again makes its appearance and persists to 316 feet. At 316 feet the black rock is displaced once more by the porphyry, and the latter forms the core to 346 feet 10 inches. At this depth the black rock once again comes in, but persists only to a depth of 350 feet. At 350 feet there is once again a clean cut junction with the porphyry, and this rock constitutes the core to the end of the bore.

Of the albite porphyry nothing further need be stated. The black rock, however, possesses such uncommon features that a somewhat detailed description of it is called for.

When fresh, the rock is black, of medium to fine grain, and unsheared. In places, particularly at and near its contact with the porphyry, it is aphanitic and almost glassy or flinty in texture. It decomposes at first to a dark-gray rock with white spots and finally to a grayish-white soft porous facies of comparatively small specific gravity. The specific gravity of the least decomposed specimens obtainable is 2.96. Under the microscope the constituent minerals of the rock are:—olivine, augite, felspar, magnetite, a carbonate, talc, chlorite, picotite.

Olivine is by far the most conspicuous mineral in the sections and forms about one-sixth to one-third of the normal rock. It occurs as large rectangular crystals wtih acute pyramidal terminations as large and small squarish crystals, and as rounded and irregular grains of different sizes. In some forms, traces of a cleavage //010 can be made out, and in all forms there are the usual irregular cracks and the shagreen surface. When the mineral has become somewhat decomposed it is replaced (in the larger crystals) by serpentine and magnesite or dolomite, or by the carbonate with hardly any serpentine; in the smaller crystals, by talc and the carbonate or by either talc or the carbonate alone. In those crystals in which the alteration is wholly to talc the crystal form has usually been preserved, but in those in which the alteration is to a carbonate the squarish or rectangular shape has been changed wholly or in part to a rounded one.

The mineral occurs in phenocrysts both large and small in a fine-textured reticulated ground-mass, and in nearly all the sections it forms the only phenocrysts. In very rare instances, the crystals

appear to have a thin border of augite. Careful examination of some sections shows that there is a small development of a second generation of olivine in rather minute squarish as well as round crystals. The squarish forms were at first thought to be cross-sections of augite prisms, but the absence of the characteristic pyroxene cleavage and the fact that the extinction in the forms is parallel to a side and not to the diagonal of the squares shows that the mineral cannot be augite. Moreover, in the aphanitic facies, similar small squares occur, some of which being now filled with talc have undoubtedly been olivine.

Augite occurs either in minute shapeless grains or in small prismatic or acicular forms in the ground-mass. The size of the grains and needles is so small that it is generally extremely difficult to identify the mineral, and it is only by the fact that the prismatic or acicular crystals give extinction angles up to 37deg. and exhibit twinning with the twin plane and composition plane 100, that the mineral can be identified. In the normal facies of the rock, the mineral occurs as minute rods, plumose aggregates of rods, linear aggregates of grains, or as individual small grains in the ground-mass, and the rods and aggregates form a minute network or plexus which closely resembles that of the felspars of some basalts. The prismatic forms are in places frayed or fibrous at one end and are somewhat similar to the microclites of some glassy basalts.

Felspar occurs noticeably in some facies and hardly at all in others. In all sections, it is present as minute microclites distributed in all directions in the ground-mass. The needles are so fine that they are only with difficulty discernible, but not uncommonly they are long and arranged in sheafy aggregates, the individual microclites being separated by granules and strings of granules of augite and of magnetite.

Magnetite occurs in fine granular form or as a fine dust scattered through the ground-mass, particularly in the facies in which the felspar occurs as long thin needles arranged in divergent groups and separated by linear aggregates of augite. In some sections it is present as a border round olivine grains that have been replaced by talc or the carbonate. Talc and dolomite or magnesite occur as decomposition products of olivine, chiefly replacing this mineral; and the chlorite scales have most probably been derived from the decomposition of augite.

Picotite is present in the rock in the form of small squarish or lozenge-shaped grains which are semi-transparent in the sections and of a deep brown colour. A few of the crystals were isolated by crushing the rock to powder and they proved to be octahedral in form. Moreover, partial chemical analysis of the rock gave .2 per cent. of chromium oxide, and this, together with the crystallo-

graphic and optical characters of the mineral, leaves little room for doubt as to the identity of the mineral. The picotite is almost wholly associated with the olivine in the rock.

Structure of the Rock.—The structure of the rock varies within a comparatively wide range. In the one facies there are large rounded, angular, and euhedral crystals of olivine in a very fine ground-mass composed of a network of minute prisms and grains of augite, granules of olivine, and a very minute plexus of felspar microlites, together with scattered granules of magnetite and the squarish crystals of picotite. At first sight the ground-mass appears to be made up of a plexus of *felspar* microlites and grains of augite, but more careful observation shows that the felspar forms only a small and almost indistinguishable part of the mass, and that the chief element of the ground is augite in very thin needles or rods, some of which show symmetrical extinction angles about 37deg.

In other facies there are phenocrysts of olivine of different sizes and small prisms of augite in a ground-mass of fan-shaped, sheaf-like and divergent groups of felspar microlites separated by minute needles of augite and granules of magnetite. This structure is somewhat similar to that found in variolitic basalts and in the glassy selvages of other basalts. In a few sections, particularly in those from the flinty facies, there are numerous euhedral crystals of olivine and prisms of augite in an extremely minute dark-grayish nearly black ground-mass which is of the variolitic type and almost irresolvable, but which on examination by high powers proves to be of similar composition to that of the coarser facies, with the felspars as mere threads.

Both in composition and in structure the rock bears a close resemblance to fine-grained olivine-basalts such as are found amongst the lowest lavas in the Bathgate Hills in Linlithgowshire in Scotland. The porphyritic character of the olivine, the presence of two generations of the mineral, the ground-mass composed of a plexus in part of augite, in part of felspar microlites, the sheaf-like or divergent grouping of the felspar needles and the large amount of fine granular magnetite scattered through the mass are features which link the rock with olivine-basalts.

On the other hand, the exceptionally large development of olivine, the fact that the differentiation of the ground-mass and phenocrysts is in places not at all well marked; that indeed in places there appears to be no ground-mass at all; the fact that the felspar in places almost wholly fails and the rock becomes a type composed largely of olivine and augite, these are characters which equally ally the rock with the ultra-basic plutonic picrites. Even in one and the same section of the rock can be seen parts resembling both in composition and structure olivine basalts and parts equally resembling ultra-basic picrites.

The most significant feature of the rock so far as its relationship is concerned is, however, the presence of picotite in all facies except perhaps the glassy selvages. Picotite is common in ultrabasic plutonic rocks and may be regarded as characteristic of some types of them, but so far as can be ascertained, it is not known to occur at all in olivine-basalts of extrusive origin. Even if it does occur in the latter in rare instances, the amount present cannot possibly be comparable to that in the rock under consideration. The presence of picotite, therefore, in addition to the characters mentioned above, clearly shows that the rock is really a picrite, that is, a type of ultra-basic plutonic and not an extrusive olivine-basalt. It is, in fact, a porphyritic olivine picrite with resemblances both to normal picrites and to somewhat glassy olivine-basalts, and is to be regarded as a hypabyssal representative of the plutonic picrites or peridotites. So far, such rocks have received but little notice from petrographers. Schemes of rock classification have made no provision for them. The differences between abyssal, *i.e.*, plutonic, and hypabyssal, *i.e.*, intrusive types amongst the acid, intermediate, and basic rocks are of course so conspicuous that distinctive names for the types have long been given; but as the differences between the abyssal and hypabyssal types among ultrabasic rocks are less conspicuous, no name has yet been given them, though these differences are noteworthy and significant.

Occurrences of a Similar Rock.—There are very few recorded occurrences of rocks of the peculiar character of this core in other parts of the world, but in his book on the Tertiary Igneous Rocks of Skye, Harker has described a sill which is almost identical both in composition and structure. According to him, the rock is dark, dense, of Sp. Gr. 3.14, showing abundant fresh olivines in a fine-textured ground. The mineral occurs in a second generation forming more or less rounded grains. Octahedra of picotite are present. The ground-mass consists mainly of innumerable slender rods of felspar with interstitial augite, the felspars having an arrangement as in many so-called variolites. The rock is mineralogically a picrite, its special features being the porphyritic development of olivine and the quasi-variolitic structure of the ground-mass.

In Western Australia itself a very similar rock has been recognised by the present writer from St. Ives District. It was first found 3 feet below the surface in a costeen 120 feet south of No. 3 shaft in Lease 4720, Ives' Reward, and a probable continuation can be traced in the next lease to the east, where the rock strikes roughly east and west and appears to cut a jasper bar at right angles. From the mode of occurrence of the rock in the Reward, cutting across the shear planes of the greenstone in which it occurs, it is most probably a dyke.

The rock is essentially th e same both in composition and structure as the core from the British Flag Lease, though it differs in minor points. It is coarser in texture, and even in one section there are several abrupt changes from fine to coarse-textured facies. Apparently the rock before consolidation was very fluid, and portions subjected to sudden cooling formed fine-textured masses. The cooling of the whole rock, however, was so swift that the later-cooling portions had not time to react on the finer and earlier-cooled portions.

Field Relations of the Rock.—As already shown, between 267 feet and 350 feet in the core, the picrite is encountered three times, and each time, after persisting for some feet, it is displaced by porphyry. There can be little doubt, therefore, that the rock really occurs as tongues in this porphyry. Moreover, the black strings and veinlets, which though at first taken for picrite proved to be composed of calcite stained black by carbon, owe their origin, at least indirectly, to the picrite, for examination under the microscope of the junction between the two rocks shows a connection between the veinlets and the black rock, and as no carbon is present in the porphyry itself, it must have come in when the picrite was intruded. Again, the black rock at its contact with porphyry exhibits an aphanitic and more or less glassy selvage, whereas the porphyry never shows any selvage on the black rock. These facts, together with what is known of the mode of occurrence of the similar picrite in Ive's Reward, indicate that the picrite of the core is a dyke which is intrusive into the albitic porphyry and is consequently younger than it.

The Geological Results of the Examination of the Cores.

1. Those from Maylands Lease: The graphitic slate encountered in the bores on the Maylands Leases is both in mineral and chemical composition and structure much more probably of sedimentary than of igneous origin.

The relations between the graphitic slate and the porphyrite in the No. 2 Bore show that the porphyrite is intrusive into and consequently younger than the graphitic slate and also that a junction between the slate and porphyrite is very close to the site of these bores.

Moreover, the occurrence of the bornblende porphyrite in the bores shows that there is (between Hannan's Lake and the site of the bores) a belt of porphyrite which is continuous with that at Monument Hill and which in all probability is the same as that at Bulong. A considerable amount, therefore, of the area near the Lake mapped as amphibolite on Gibson's plan of Kalgoorlie and Boulder should be mapped as hornblende porphyrite so that neither

time nor money will in future be spent in prospecting it either by shafts or by bores. It is of course impossible with the knowledge at present on hand to fix the boundary of the porphyrite, but its northern limit appears to be near the site of the bores, and the belt most probably extends to Bulong.

2. Those from the Lady of the Lake Lease and from Reserve 288H prove that there is a much larger area of albitic porphyry south of Boulder than it has previously been possible to show on the geological maps, and very considerable areas marked on the 10-chain geological map of Kalgoorlie of 1902 as amphibolite, and on Gibson's 30-chain map of Kalgoorlie of 1910 as quartz diabase, should be marked as albitic porphyry. There is, in fact, good reason for stating that all porphyry dykes on the 10-chain 1902 map can be joined along the strike and the country between them is most probably also porphyry, and, as such, of little value for prospectors.

3. Leases 5177, 5178, 5072, of Mr. Williams: The cores from these leases prove that there is a belt of amphibolised quartz dolerite, *i.e.*, of rock very similar to the country rock of the Golden Mile, extending to the south of the Black Crow-Starlight-Lake View Extended line, beyond which no really valuable lodes have yet been found. How far the belt extends either north and south, or east and west, is not yet known, though bores now being put down may prove its limits. In that belt there does exist a possibility of the discovery of some lode of value, though the absence from the core up to the present of the facies showing pronounced shearing and shearing and mineralisation combined must be regarded as not altogether a favourable augury for the future.

4. *The British Flag Lease.*—The porphyry met with in this bore almost at the surface and extending down to at least 350 feet supports the statement made above that the area occupied by this rock is much larger than was thought. The chief interest of the rock, however, from the geological viewpoint is the occurrence of the picrite dyke. This rock is not only quite new so far as our knowledge of the petrology of Kalgoorlie is concerned, but if we except the rock from Ive's Reward, no similar rock has been recognised in the State, and only in very few localities in the world do rocks of the same nature occur.

Moreover, as it is younger than the albitic porphyry, it is undoubtedly the last rock to be intruded in the field. Whether it has arisen from the same magma and is of the same geological age as the olivine gabbro intrusions of the Warburton Range, or is the hypabyssal equivalent of the Bunbury basalt, are questions which cannot yet be answered, but as it is well known that particular rocks are intruded in different parts of the world at the same time the age of similar rocks in other parts of the world suggest that it is of comparatively recent origin.